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Application of a mean-field model for brittle creep strain rates under finite loading conditions

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In many instances, the approach to earthquakes, volcanic eruptions and landslides may be controlled by brittle failure of the Earth's crust. If brittle deformation signals (e.g. strain and seismicity) are to be used for quantitative forecasting of such phenomena, it is important that we can first model and forecast brittle failure under controlled laboratory conditions. Here we describe a simple damage model for deformation during laboratory brittle-creep experiments and develop a methodology for applying it to real and synthetic data. The model is based on separate transient and accelerating sub-critical crack growth mechanisms, associated with separate processes of negative and positive feedback in the population dynamics, and also corrects for the finite loading rate. It reproduces the classic 'bathtub' graph observed in seismic event rate, seismic moment release rate and rate of porosity change during brittle-creep experiments. We describe an iterative maximum-likelihood method to fit the model to experimental data, which successfully recovers the input parameters for synthetic brittle-creep data. We apply the model to a suite of brittle creep experiments conducted on Darley Dale Sandstone and Mount Etna Basalt conducted at different fractions of the failure stress. For high fractions of the failure stress, the model fits the experimental data well. Remarkably, the transient decays with an exponent near unity, as commonly observed for natural earthquake sequences and the creep rate accelerates towards failure again with an exponent near unity. At lower fractions of the failure stress (slower experiments), the data deviates systematically beyond the expected model uncertainties, suggesting the action of processes not captured by the mean-field model approximation. We go on to consider how such a model can be applied in a prospective forecasting scenario.